

AFRL's Multi-Satellite Deployment System (MSDS)

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Abstract

One new way to perform missions from space is the concept of clusters of microsatellites that operate cooperatively to perform the function of a larger, single satellite. Each smaller satellite communicates with the others and shares the processing, communications, and payload or mission functions. The Air Force Research Laboratory (AFRL) is exploring this new paradigm for performing space missions in a partnership program with AFOSR, DARPA, STP and GSFC, called the University Nanosatellite program. Through this program, AFRL is sponsoring the development and launch of 9 university designed and built nanosatellites. The universities are pursuing creative low-cost space experiments to explore and demonstrate the usefulness of nanosatellites in such areas as miniature bus technologies, formation flying, enhanced communications, distributed satellite capabilities, and maneuvering. The satellites are planned to launch on two Shuttle flights in early 2003. The knowledge gained from this program will aid other Air Force programs such as TechSat-21.

The Air Force Research Laboratory is also contributing to this effort by designing and building a Multi-Satellite Deployment System (MSDS). The MSDS is a platform designed to deploy multiple satellites to low-earth orbit using the Shuttle as the primary launch vehicle. The MSDS consists of an aluminum platform with two mounting locations, each of which can support a stack of one or more Nanosatellites. The MSDS/Nanosatellite system is attached to the Shuttle Hitchhiker Experiment Launch System (SHELS), and the entire assembly is installed in the Shuttle Payload Bay. Contingent on the success of the University Nanosatellite program first flights, the MSDS will be a viable platform for the launch and deployment of future small satellites.

University Nanosat Program

Overview

The University Nanosat program consists of nine nanosatellites (nanosats) designed and built by eight universities, which are baselined to deploy from Shuttle via SHELs in two separate flights. The satellites are organized into four subclusters (stacks) for purposes of demonstrating formation flying, inter-satellite collaborative processing/communication, and autonomous control operations and data downlink. The nanosatellites also each incorporate unique technology demonstrations and science measurement capabilities, including ionospheric measurement, micro-propulsion and variable drag. The first flight consists of three satellites designed and built by Stanford University and Santa Clara University. The second flight consists of six satellites designed and built by Utah State University, the University of Washington, Virginia Tech, Arizona State University, the University of Colorado at Boulder, and New Mexico State University. On each flight, the satellites are arranged in two stacks that will

be deployed simultaneously from AFRL's MSDS. Each stack is mounted to the MSDS via two low-shock, shape memory alloy (SMA) separation systems referred to as the Stack Separation Systems (SSS), which are being developed by the Starsys Research Corporation under contract to AFRL. The individual nanosats are attached to each other in these four stacks by a *Lightband* inter-satellite separation system furnished by the Planetary Systems Corporation. The first flight (Nanosat-1) consists of two stacks, designated Emerald and Orion (see Figure 1 for Nanosat-1 General Arrangement). The second flight (Nanosat-2) consists of two stacks of hexagonal nanosats designated Three Corner Sat (3CS) and ION-F (see Figure 2 for Nanosat-2 General Arrangement). When integrated, the MSDS, nanosat stacks, and separation systems are referred to as the system. The Nanosat system is attached to the Shuttle Hitchhiker Experiment Launch System (SHELs) via an adapter mounted to the bottom surface of the MSDS. The entire assembly, including the SHELs, is installed in the Shuttle Orbiter Payload Bay.

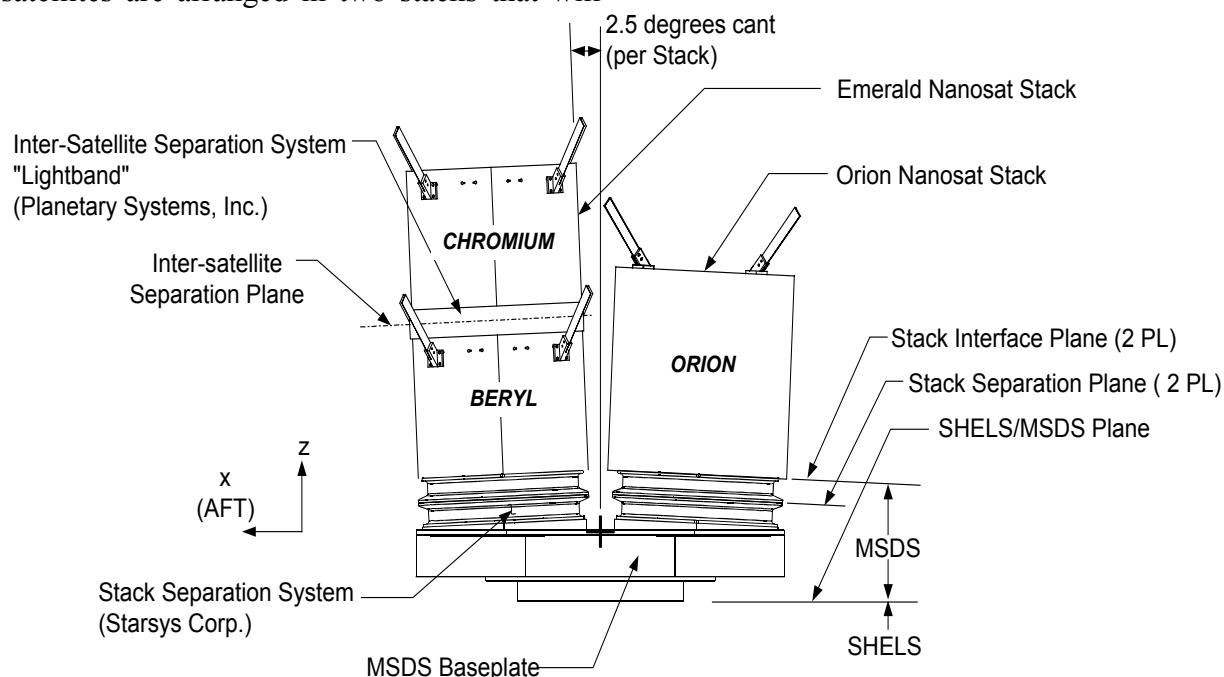


Figure 1: Nanosat-1 General Arrangement

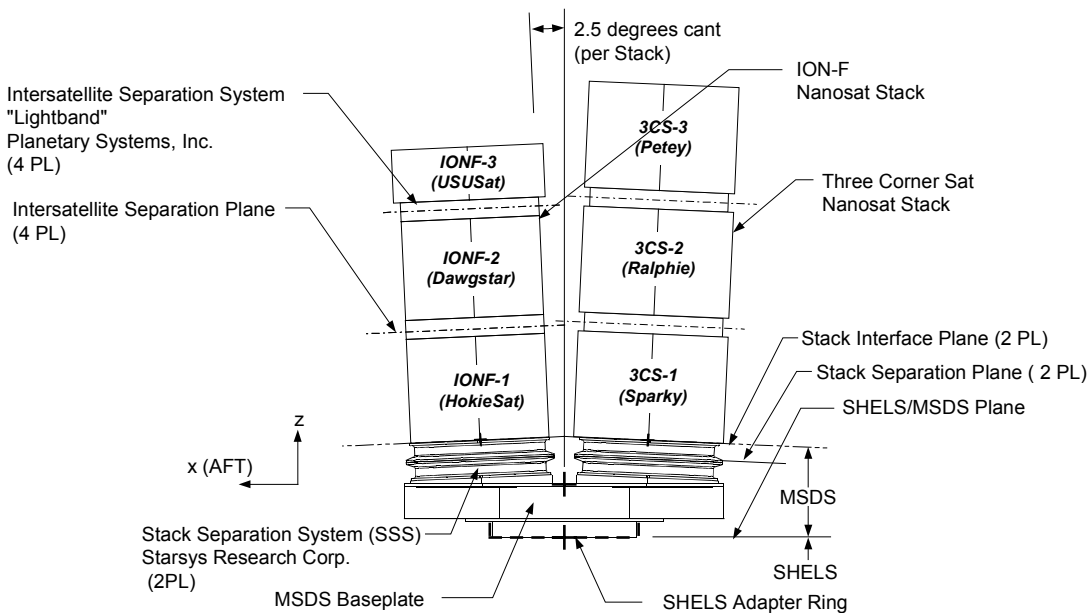


Figure 2: Nanosat-2 General Arrangement

Deployment Sequence

While the Nanosat system is in the Shuttle bay, it is a must-not-work system, meaning that no power may be supplied to mechanisms that may become a hazard to the Shuttle if powered. Deployment and operation of Nanosat hardware occurs in five phases for each flight. The Nanosat-2 general arrangement is used to show this deployment sequence in Figure 3. At T0, ejection of Nanosat-2 from SHELS will trigger the start of timers on the MSDS via microswitches at the Nanosat/SHELS separation plane.

At T1 (20 minutes), the MSDS will issue a signal to the nanosats via electrical connectors in the SSS. This T1 signal will be used to remove safety inhibits for all systems except those identified as recontact hazards. The T1 signal allows Nanosats to begin certain operations that do not pose a recontact hazard

to the Shuttle. Such operations include battery charging, RF communication, verification of position/attitude, etc.

Safety inhibits for *recontact hazards* are removed at T2, which occurs 96 hours after ejection of Nanosat-2 from SHELS. Recontact hazards include such systems as stack and intersatellite separation systems, propulsion systems, and deployable hardware. The four-day delay between T1 and T2 is intended to provide the Shuttle with ample time to return to Earth.

At T3, an activation signal is simultaneously sent to both SSS's, resulting in separation of both stacks from the MSDS. At time T4, the intersatellite separation system will be activated by the Three Corner Sat and ION-F stacks, or the Orion stack in the case of Nanosat-1.

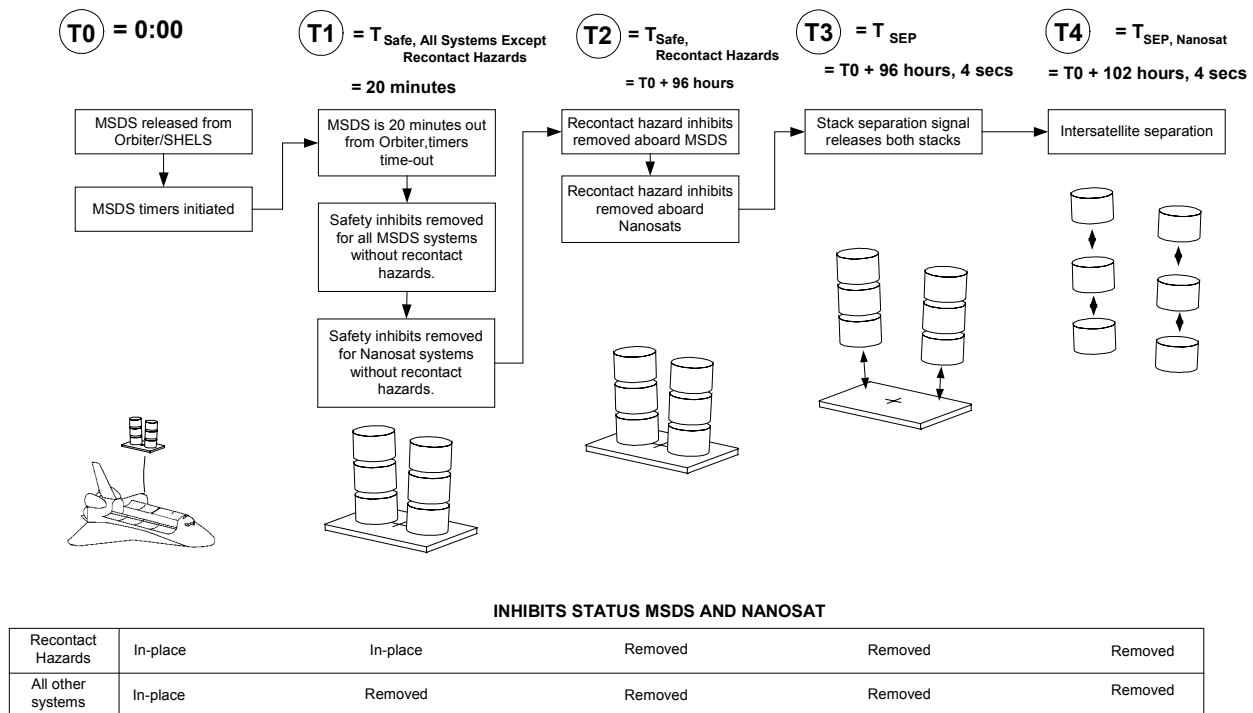


Figure 3: Nanosat-2 Deployment Sequence

Orbiter / MSDS Performance Parameters

An altitude of 300-400km, and an inclination of 28°-40° is desired for ejection of the Nanosat payload from the shuttle. Exact altitude and inclination will be subject to NASA mission requirements and approval. MSDS/Nanosat capabilities (i.e., Stack separation and Nanosat propulsive capabilities) were considered in a safe distance assessment. The Nanosat Program has requested safety inhibit disablement at 4800 ft from the Orbiter, which corresponds to a separation speed of 4 ft/sec for 20 minutes.

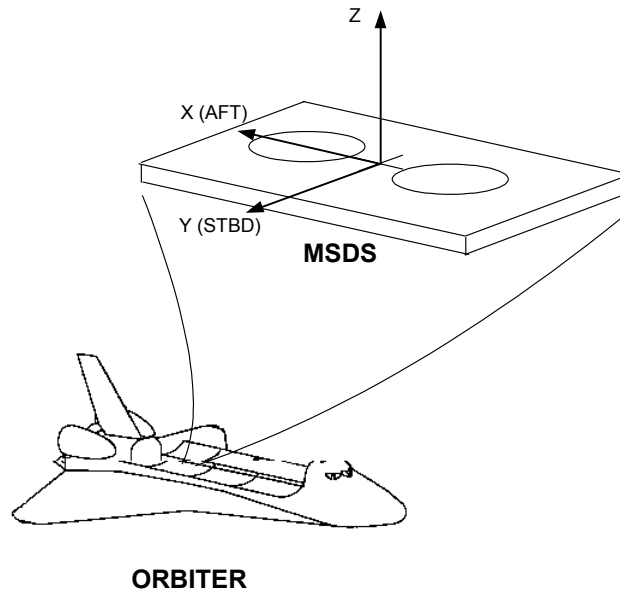
MSDS

MSDS General Description

The MSDS is a platform designed to deploy multiple satellites to low-earth orbit using the Space Shuttle as the primary launch vehicle. The MSDS consists of an

aluminum platform with two mounting locations, each of which can support a stack of one or more Nanosatellites (Nanosats). The MSDS/Nanosat system is attached to the SHELS, and the entire assembly is installed in the Shuttle Orbiter Payload Bay (Figure 4).

Each satellite stack is canted 2.5° from the MSDS Z-direction in the MSDS X-Z plane. The total divergence between the two satellite stacks is 5°. This divergence angle provides a relative separation velocity between the stacks when they are launched simultaneously from the MSDS. In addition, the two stacks will be released at different speeds in order to preclude asymmetric transfer of stack momentum to the MSDS during stack separation. There are no further provisions for stabilizing the MSDS.



Note: The SHELs system may be installed on either side of the Shuttle Payload Bay. For the purposes of description and analysis, a port side installation is assumed.

Figure 4: MSDS Coordinate System

The MSDS consists of three major subsystems: 1) structure, 2) power supply, and 3) stack separation. The MSDS Structural Components are shown in Figure 5. The MSDS is a 36" x 20" x 5" rib-stiffened aluminum platform consisting of an upper plate, a lower plate / SHELs adapter ring, and systems to support removal of nanosat

electrical safety inhibits and separation of nanosat stacks. The MSDS weighs approximately 176 lbs, including the baseplate / SHELs adapter ring, SSS, MSDS battery, and balance weights. In order to meet the c.g. requirement for SHELs payloads, the MSDS has provisions for balance weights to offset weight differences in the two stacks.

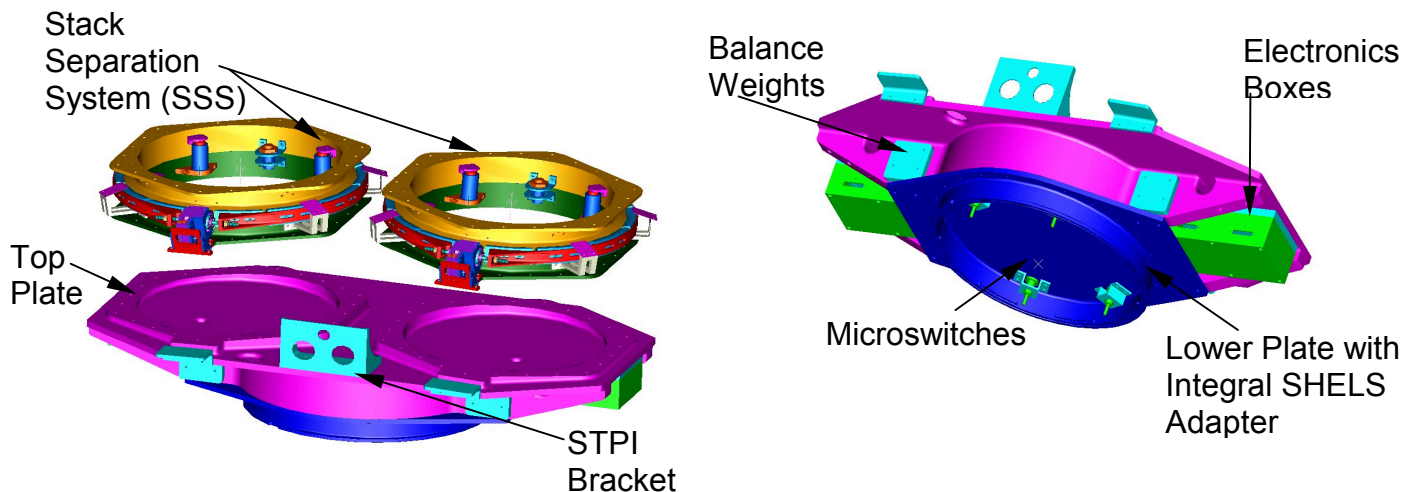


Figure 5: MSDS Structure Components

Orientation & Payload Physical Envelope

The Stack Interface Plane (SIP) is canted at 2.5° relative to the X-Y plane (Figure 6). When the two Nanosat stacks are deployed from the MSDS, this cant angle induces a stack relative separation velocity (note that

the total angular separation between stacks is 5°). The geometric centerline of the stack shall be normal to the SIP and coincident with the reference stack centerline shown in Figure 6.

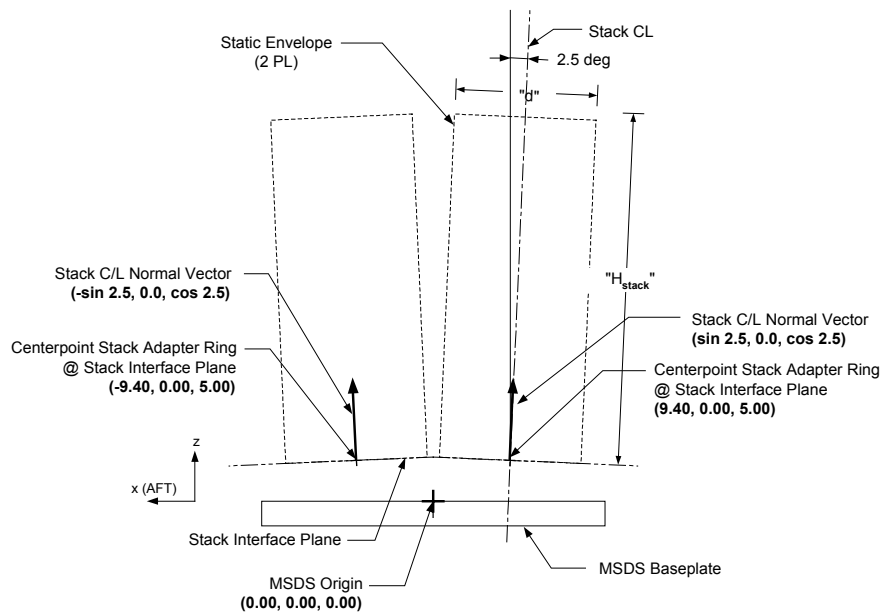
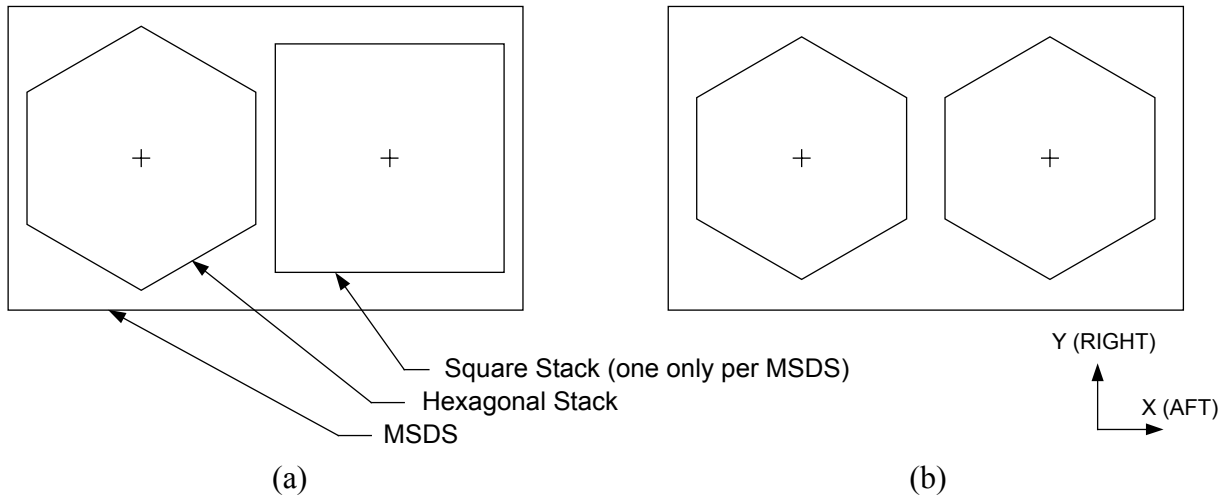


Figure 6: Orientation of Stack Centerline and Stack Interface Plane

When mounted to the MSDS, Nanosat Stacks must be oriented with a flat side parallel to the MSDS Y-direction. Example configurations are shown in Figure 7. These figures are not meant to convey any particular launch order, and other configurations are possible. However, because of space constraints on the MSDS, only one square stack (i.e. stack with a

square footprint) is permitted per MSDS. This square stack must be paired with a hexagonal stack (or dummy payload) whose dimensions fall within the constraints imposed by Table 1 and Figure 9. Two hexagonal stacks meeting the same requirements can be placed on a given MSDS.



Note:

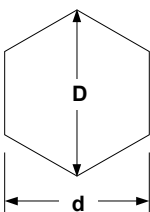
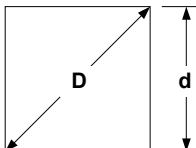
In this figure, Nanosats footprints are not shown in true view. The centerline of each stack is offset 2.5° from the z-direction. Each stack should be oriented such that a flat surface is parallel to the MSDS Y-direction

Figure 7: Nanosat Stack Orientation about Stack Centerline

The static envelope defined for the individual Nanosat stacks is characterized as either a hexagonal or square right prism based at one of two locations on the MSDS. The envelope is defined in such a way as to allow for a 2.5° cant angle provided at the base of the stack. The Nanosat minor

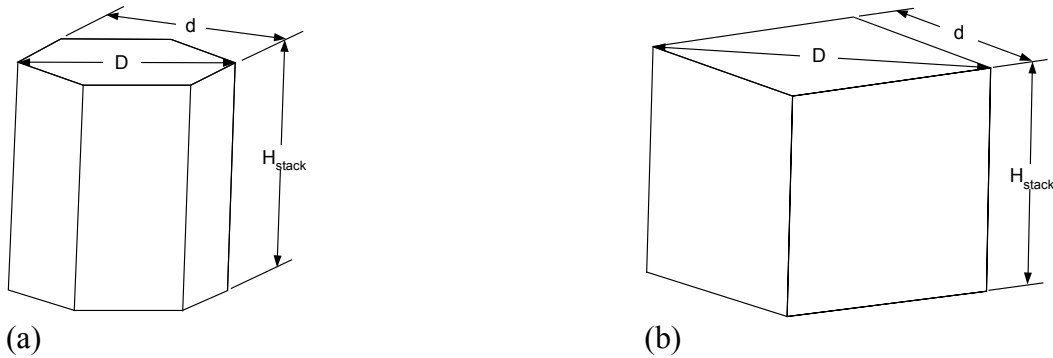
diameter is defined as the distance between two opposing side faces of the satellite, while the major diameter is defined as the distance between two opposing corners. Table 1 provides a summary of acceptable Nanosat shapes and sizes.

Table 1: Acceptable Nanosat End-Face Geometry

Footprint	Max Major Diameter (D_{\max}) Max Minor Diameter (d_{\max})
Hexagonal 	$D_{\max} = 20.0''$ $d_{\max} = 17.3''$
Square 	$D_{\max} = 24.5''$ $d_{\max} = 17.3''$

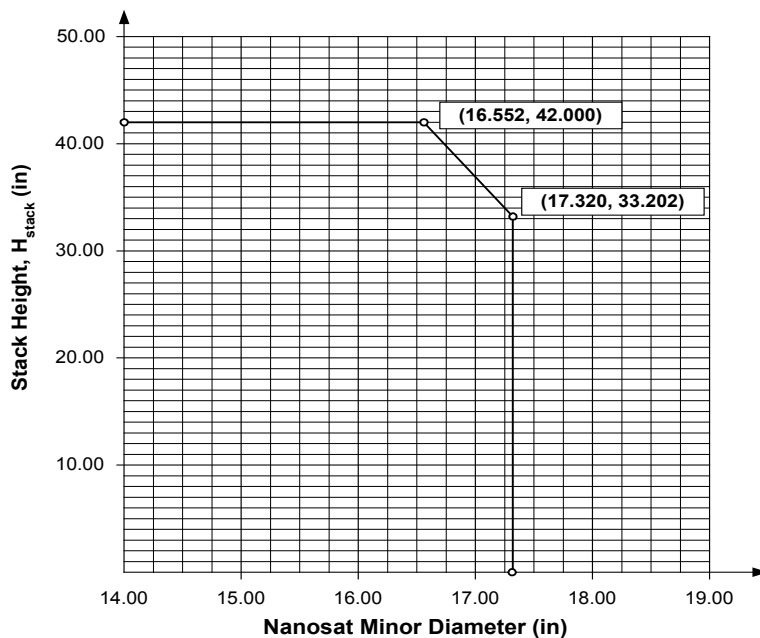
Stack height (H_{stack}) is defined as the distance between the Stack Interface Plane and the opposing (unattached) nanosat surface, as measured along the centerline of the stack (Figure 8). This dimension shall include all protrusions. The allowable H_{stack}

is limited by several variables, including the height and width of the MSDS envelope, Nanosat diameter, and cant angle. For a given Nanosat Stack, H_{stack} must be equal or less than the boundary values shown in Figure 9.



Note: Satellite stacks shown may consist of one or more individual Nanosats

Figure 8: Nanosat Stack Physical Envelope Nomenclature



Note: Dimensions shall include all applicable manufacturing tolerances

Figure 9: Allowable Stack Height, based on a 2.5° cant angle & 1.5 in Interstack Clearance

Mass / Center of Gravity and Fundamental Frequency Requirements

The baseline mass of each Nanosat Stack is less than or equal to 50 kg. The stack mass includes all mass above the SIP, including bolts used to attach the Stack Separation System upper adapter ring to the bottom

Nanosat. The CG for each Nanosat Stack is to fall within 0.25" of the SIP normal vector (Figure). In addition, the CG is to not lie more than 20 inches above SIP (+Z). Each Nanosat Stack is required to have a fundamental frequency above 100 Hz given a fixed-base condition at the SIP.

Power Supply System

The MSDS battery is a 33 volt NiCd rechargeable battery with a capacity of 4.5 amp-hours. The battery consists of 22 Sanyo N4000 DRL cells enclosed in a battery box. The battery box is constructed of Al 6061-T6, with a stainless steel internal rib for mounting the batteries. A silicone rubber gasket is installed between the cover and box. To absorb electrolyte in the event of a leak, sheets of Pigmat MAT301 is installed in the battery box, above and below the cells.

The MSDS power supply system is shown in Figure 10. The purpose of the system is to: 1) remove nanosat electrical system safety inhibits, except those for recontact hazards, at time T1, 2) remove nanosat electrical safety inhibits for recontact hazards at time T2, and, 3) activate the two SSS at T3.

The MSDS power supply system functions as follows: At T0 = ejection from SHELS, four microswitches MS-1 through MS-4 are switched to the closed position. Power from the battery then becomes available to system timers allowing them to initiate. Note: at this stage, power is prevented from reaching any system functions other than the timers since LR1-8 are in the open position. Two signals, T1 and T2, are then provided by the MSDS power supply system at times T1 and T2, respectively, to disable nanosat inhibits. Signal T1 is sent twenty minutes after Nanosat-2 deployment from SHELS. Signal T2 is sent four days later, after the Orbiter has landed. The SSS is activated at time T3, 32 seconds after signal T2. Timing of the T3 signal is provided by one of the T2 timers as discussed later.

The MSDS electrical system employs timers, microswitches, and latching relays to ensure that four inhibits are in place for all hazardous functions until the appropriate time. Inhibits LR1- LR4 prevent the T1 signal from reaching the nanosats before time T1, and inhibits LR5 - LR8 prevent the T2 and T3 signal from occurring prior to T2. In each case, one inhibit relay is in the battery return (inhibits LR4 and LR8) and three inhibits are in the power supply side. No inhibits are monitored. The combination of four inhibits with one in the return leg allows for the required "Unpowered Bus Exception" for Shuttle. The MSDS power supply system is two-fault tolerant against having power reach the SSS or send the T1 or T2 signals to the nanosats before the safe time.

The T1 and T2 signals will be conducted to the nanosats through electrical connectors installed at the Stack Interface Plane. There are two connectors for each stack for a total of four connectors. The connectors are labeled A1, A2, B1, and B2 in Figure 1. Connectors A1 and B1 conduct the T1 signal to each stack, respectively, while connectors A2 and B2 conduct the T2 signal to both stacks. Therefore, the T1 and T2 circuits are physically separated from each other. These connectors are the only electrical interface between the nanosats and the MSDS.

The Lightband intersatellite separation system is operated by the nanosat power systems. The Lightbands are considered to be a recontact hazard and, therefore, will not be activated until after the T2 signal has been sent. Premature activation is prevented by inhibits internal to the nanosats. The intersatellite separation systems will be activated at time T4.

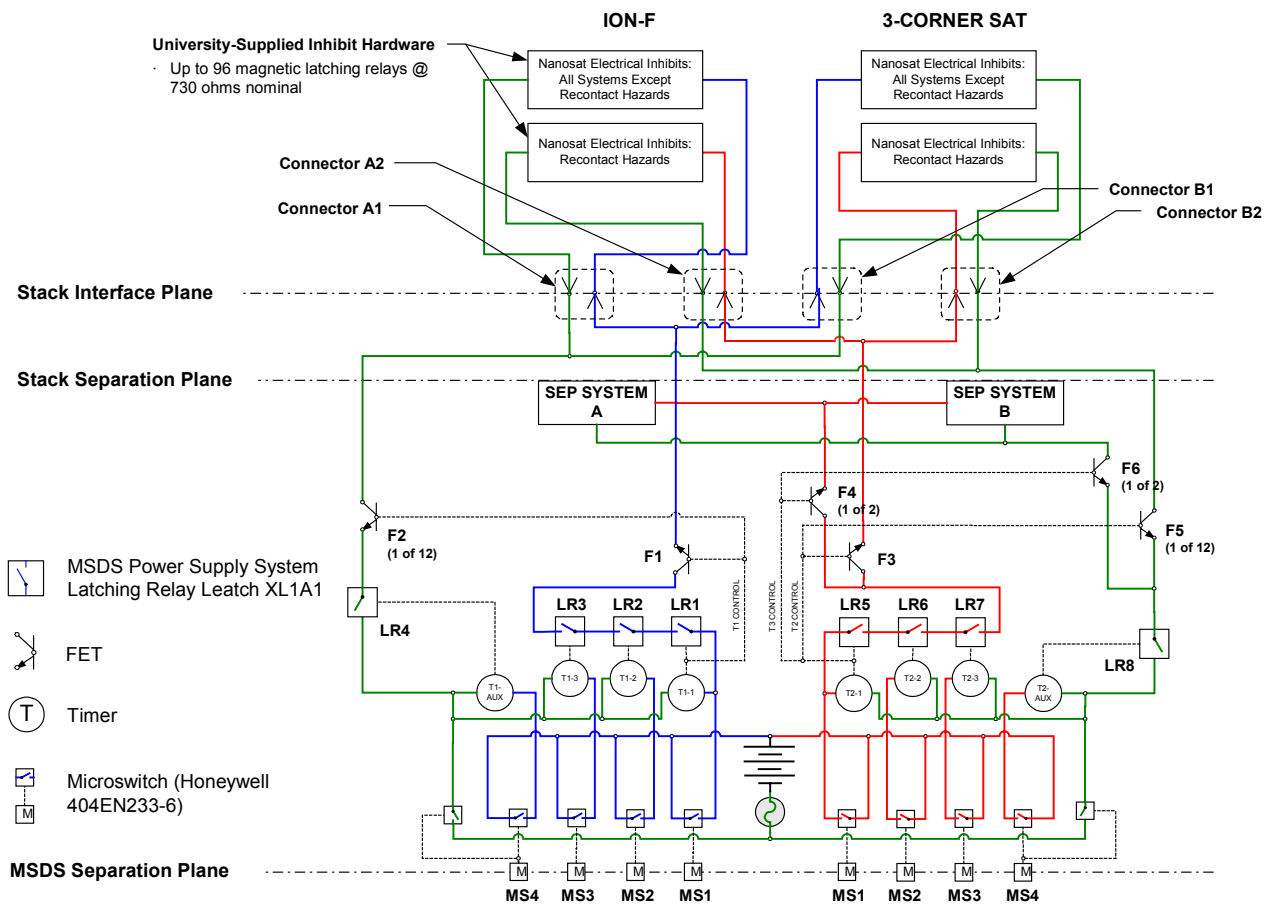


Figure 10: MSDS Electrical System Concept

MSDS/Stack Interfaces

Mechanical Interface

The Nanosat Stack is mounted to the MSDS via the Stack Separation System. The separation system consists of three major components. The upper adapter ring is bolted to the base of the Stack at 24 locations. The lower adapter ring is bolted to the MSDS Baseplate at 24 locations. A V-Band clamp is used to attach these two rings together, thereby connecting the Stack

to the MSDS.

The universities provide attachment locations at the base of the Stack. These locations correspond with fastener locations on the upper adapter ring (Figure 11). This interface forms the basis for the SIP shown in Figure 2. Nanosat hardware can not extend beneath the SIP.

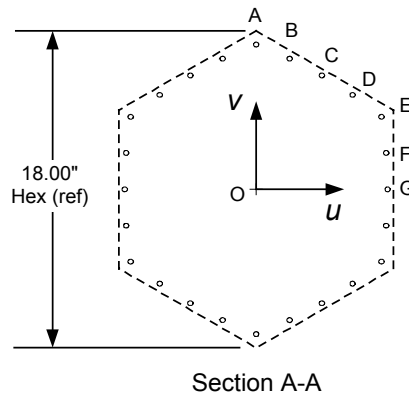


Figure 11: Nanosat Stack Mechanical Interface

Electrical Interface

The Stack Interface Plane represents the interface between AFRL and university hardware. Below this plane, AFRL will provide two D-subminiature connectors (male) for the purpose of conducting the T1 and T2 signals to each stack. Above the SIP, the stack-side T1 and T2 connectors shall be designed and installed by the universities. Starsys will incorporate two connectors into the design of the Stack Separation System. These connectors should be located within the SSS T1 and T2 Connector Envelopes shown in Figure 12.

Starsys will provide a clearance of at least 0.5 inches between the SSS connector and the nearest adjacent structure above and below the connector to avoid crimping wire bundles that must be routed to locations not in-line with the SSS Connector. Each connector will have at least 15 contacts, each with contact size supporting 22AWG wire. Starsys is responsible for SSP connector pin assignments. SRC is also installing 14" (22AWG) wire leads on the upper and lower connectors for each live pin in the SSP connector.

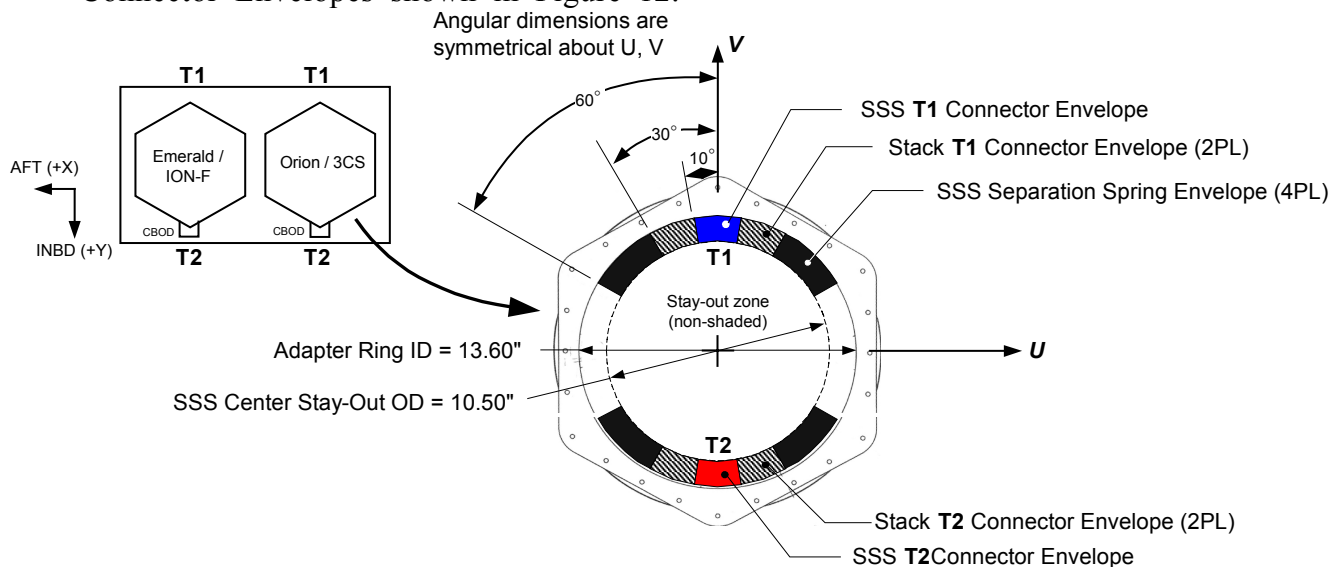
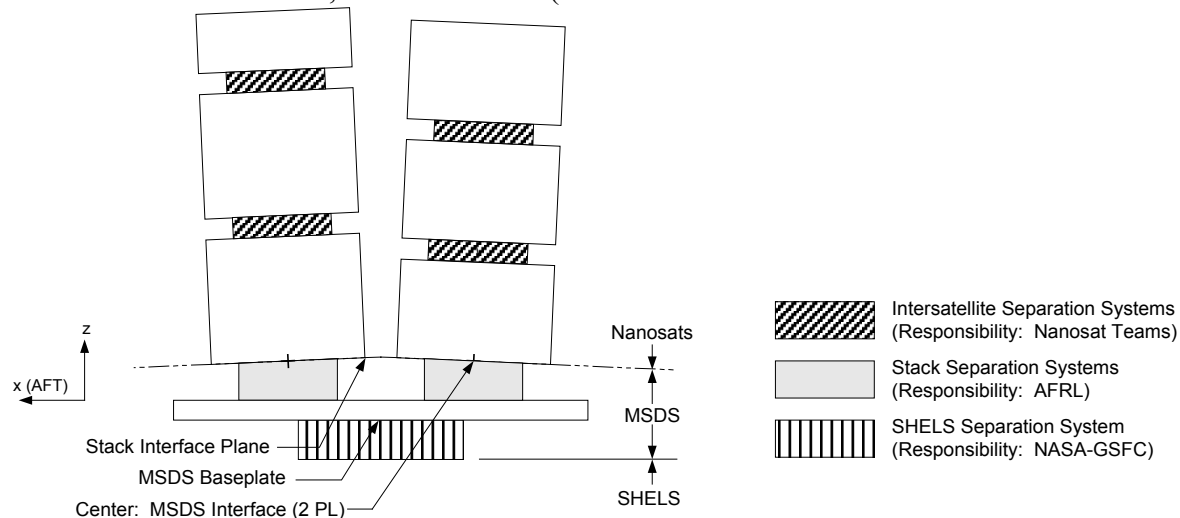


Figure 12: Nanosat Stack Electrical Interface

Separation Systems

There are three types of separation systems involved in the deployment of University Nanosats. The first system (the SHELS Separation System) releases the MSDS/Nanosat System from the Orbiter payload bay. The second system (the Stack Separation System) releases the Nanosat Stacks from the MSDS, and the third (the

Intersatellite Separation System) is used to deploy individual Nanosats. Of these systems, only the Intersatellite Separation System will be provided by the universities as part of the Nanosat Stack (see Figure 13). Note: AFRL is providing all components of the Stack Separation System, except for the fasteners used to attach the upper Stack Separation System adapter ring to the bottom Nanosat.



Note: While the Stack Separation System is provided by AFRL, fasteners used to attach Nanosat Stacks to the system shall be furnished by the university.

Figure 13: Separation System Responsibilities

Starsys Separation System

Located at the base of each stack, each Stack Separation System (SSS) consists of two adapter rings held together by a Marman band. Tension in the Marman band will keep the two adapter rings in firm contact with each other. In order to maintain band tension, both ends of the band are threaded into a mechanical device referred to as the Clamp Band Opening Device (CBOD). When the CBOD is activated, a shape memory alloy (SMA) wire within the device is used to retract a locking arm, which allows band tension energy to be converted into rotational energy of the CBOD's flywheel. Activation of the CBOD occurs after T3 (see Figure 3).

Lightband Separation System

The Lightband Separation System is a non-pyrotechnic, low shock separation system located between each nanosat. Lightband is used to effect intersatellite separation at T4 (see Figure 3). Lightband consists of a series of interlocking aluminum leaves that are held together with a Vectran retaining line. In order to function as intended, the retaining line must be subjected to a significant tension load, which is introduced by a mechanical tensioning device. In order to activate the device, a heating element is used to sever the retaining line. Springs located between the nanosats provide the separation force.

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